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VALIDITY AND RELIABILITY OF THE TEEM 100 PORTABLE METABOLIC MEASUREMENT SYSTEM

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DEPARTMENT OF NATIONAL DEFENCE – CANADA

Executive Summary

This study examined the validity and reliability or consistency of a portable gas analysis system (TEEM 100) used for the measurement of oxygen consumption. Eight males were evaluated at rest and during several work intensities while expired air was collected and analysed in series with the TEEM 100 and a reference collection system (Tissot gasometer and Ametek gas analysers). Subjects were tested on 2 separate days for comparison of 2 TEEM 100 systems. The data revealed that either collection and analysis method was reliable or consistent from day to day. However, significant and unexplained differences were found between methods for expired ventilation, expired gas fractions and the calculated oxygen consumption. These differences became greater at higher flow rates or work intensities. It was concluded that the TEEM 100 is a consistent gas exchange measurement system. Its validity, however, should be viewed with caution.

HUMAN PROTECTION AND PERFORMANCE, TECHNICAL MEMORANDUM

January 1997

Validity and Reliability of the TEEM 100 Portable Metabolic Measurement System

Background

1. The Human Protection and Performance Section of DCIEM has had a long history of measuring the metabolic rate of human subjects, ranging from resting conditions to maximal effort, and in varying degrees of environmental stress, from thermoneutral to extremes of temperature, both hot and cold. To this end, a variety of commercially available, computer-driven metabolic measurement carts have been employed. Although these carts are relatively easily transportable, they are not conducive for use in field trial settings where portability is of paramount importance.

2. Recent technological innovations have led to the development of several portable, battery-powered indirect calorimeters. One such unit is the TEEM 100 Metabolic Analysis System (Aerosport, Inc., Ann Arbor, MI). It measures expired volumes using a flat-plate orifice pneumotach. It is also one of the few units available which contains both oxygen (galvanic fuel cell) and carbon dioxide (non-dispersive infrared) sensors. All measurements are taken, calculations made and data stored under microprocessor control.
As with any new piece of equipment, one questions the accuracy and reliability of measurement. It was the purpose of this study to evaluate the validity and reliability of the TEEM 100 and to establish a certain degree of confidence in its performance.

Study 1 - Methods

3. Complete physical description and principles of operation are best outlined in the manufacturer's supplied "Operators Manual" and will not be delved into here. The TEEM 100 comes with three sizes of pneumotach corresponding to low (2-30 $L \cdot min^{-1}$), medium (10-120 $L \cdot min^{-1}$) and high (25-200 $L \cdot min^{-1}$) flow rates. Since it was anticipated that the majority of field trials would elicit a metabolic work rate anywhere between rest and 60-80% $\dot{V}O_2$ max, it was decided to evaluate only the medium flow rate pneumotach. Other researchers (2, 3, 5, 6) have compared the $\dot{V}O_2$ response with increasing workrates of the TEEM 100 against other metabolic carts. Our experience with different metabolic measurement systems has led us to believe that these systems have inherent inaccuracies, albeit small, in their measurements ("black box" phenomenon) and that results must be viewed with a conservative

degree of caution. For the purpose of this evaluation it was decided to compare the TEEM 100 against a 120 litre Tissot gasometer (W.E. Collins Inc., Braintree, MA.), with gas analyses being performed by independent, high quality gas analyzers (Ametek Model S-3A/1 O_2 and Model CD-3A CO_2, Applied Electrochemistry, Pittsburg, PA.).

4. After informed consent (Ethics Protocol No. 277) was obtained, eight males (mean± S.D. for age, height and weight: 35 ± 8.6 y, 1.79 ± 0.05 m, 76.3 ± 7.2 kg, respectively) volunteered as subjects. All were physically active and accustomed to exercise. Subjects were evaluated at rest and while walking at 4.8 $km \cdot h^{-1}$ at 0, 5, 10 and 15% grade. The duration of each workrate was five minutes.

5. Prior to each test the TEEM 100 pneumotach was calibrated for accuracy in accordance with manufacturer specifications. In addition, the gas analyzers of the TEEM 100 were calibrated at 2 points using precise gas mixtures. The Ametek O_2 and CO_2 gas analyzers were also calibrated using the same precise mixtures. The subject was best fitted with an oro-nasal mask so as to minimize any air flow leakage out of the mask. A two-way non-rebreathing valve (Hans Rudolph, Model #2700, Kansas City, MO.) was fitted in-line to the pneumotach output. This valve was then connected to the Tissot by a minimum amount of corrugated plastic tubing. After a few minutes of rest, the subject began the testing protocol. The TEEM 100 was started at time zero and was set to collect data at 60 s intervals for the duration of the test. Minutes one through four of each workrate were allocated for "purging" of the Tissot at that workrate. Minute five was reserved for data sampling. Data collected from the Tissot during the sampling phase were used to calculate $\dot{V}_E$ and $\dot{V}O_2$, according to established equations for open-circuit spirometry (1). The last minute of data for each workrate from both the TEEM 100 and the Tissot was assumed to be at steady-state and was used for statistical comparison. On a subsequent day, the subject returned to repeat the whole protocol using a second TEEM 100 unit.

6. A Fisher's F-Test was first used to validate the reliabilty of the measurements against a line of identity. A three-factor (method x day x workrate) repeated measures ANOVA was used to anlyze the dependant measures $\dot{V}_E$, $\dot{V}O_2$, % O_2 expired and % CO_2 expired. When a significant F-ratio was found a Newman-Keuls post-hoc analysis was performed to clarify differences among treatment means. For all statistical analyses the 0.05 level of significance was used.

Study 1 - Results

7. Figures 1a and 1b depict scattergrams of Tissot (Day 1) vs. Tissot (Day 2) and TEEM-1 vs. TEEM-2 for oxygen consumption, respectively. ANOVA revealed no significant differences within the two methods. The Fisher F-test confirmed no significant difference for the reliability of any given method and the line of identity. Since there was no significant difference, it was deemed appropriate to pool the data for a given method for further analyses.

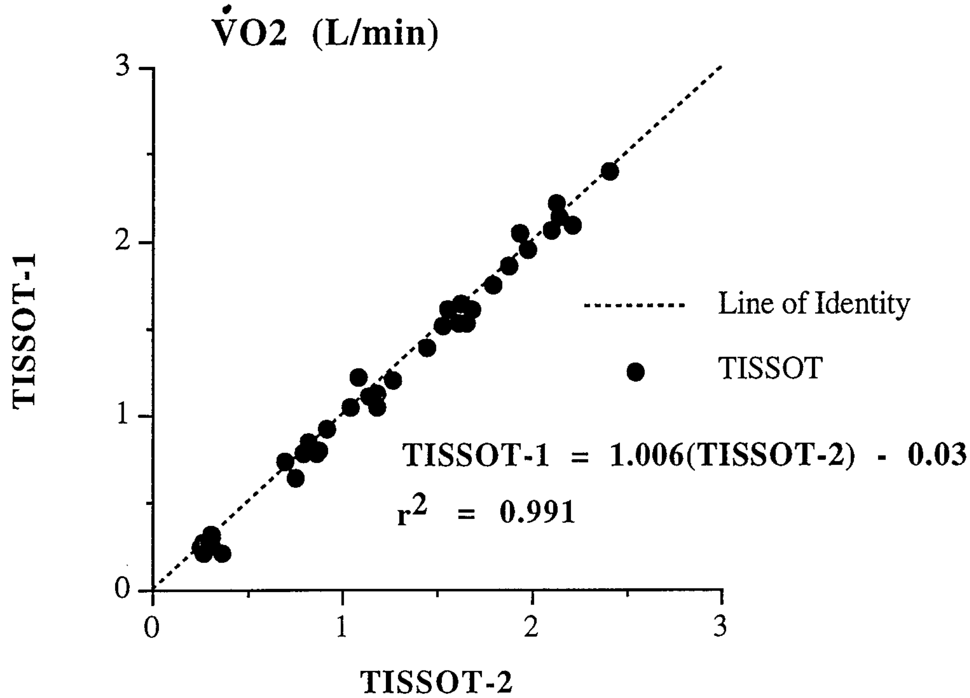
8. Figures 2a - 2d depict scattergrams of all data between the TEEM 100 and Tissot for $\dot{V}_E$, $\dot{V}O_2$, $\% O_2$ expired and $\% CO_2$ expired, respectively. Regression equations and correlation coefficients are included. ANOVA revealed highly signifant differences between the two methods for the four variables considered. A Newman-Keuls post-hoc analysis was performed and the results are summarized in Table 1.

Table 1: Newman-Keuls post-hoc analysis among treatment means (S.D.) for $\dot{V}_E$, $\dot{V}O_2$, $\% O_2$ and $\% \ CO_2$. (**tm**=TEEM 100, **ts**= Tissot, **w**=Workrate)

		$\dot{V}_E$	$\dot{V}O_2$	$\%O_2$	$\%CO_2$
w 1	**tm1**	8.08 (1.81)	0.352 (.085)	16.72 (.32)	3.63 (.15)
	ts1	7.71 (1.41)	0.258 (.042)*	17.65 (.30)*	2.89 (.32)*
w 2	**tm1**	18.25 (2.83)	0.980 (.144)	15.79 (.36)	4.21 (.27)
	ts1	16.95 (1.96)*	0.794 (.080)*	16.41 (.25)*	3.87 (.13)*
w 3	**tm1**	25.88 (2.43)	1.312 (.077)	16.03 (.36)	4.17 (.37)
	ts1	23.51 (2.12)*	1.124 (.062)*	16.26 (.29)*	4.19 (.33)*
w 4	**tm1**	34.69 (4.02)	1.831 (.160)	15.83 (.32)	4.36 (.27)
	ts1	31.54 (3.51)*	1.567 (.105)*	16.04 (.41)*	4.46 (.47)*
w 5	**tm1**	47.15 (4.61)	2.487 (.237)	15.82 (.21)	4.38 (.21)
	ts1	41.90 (4.21)*	2.090 (.163)*	16.01 (.25)*	4.61 (.36)*
w 1	**tm2**	5.75 (2.06)	0.246 (.092)	16.87 (.53)	3.33 (.32)
	ts2	8.21 (1.02)*	0.289 (.034)	17.54 (.29)*	2.91 (.29)*
w 2	**tm2**	17.70 (1.40)	0.919 (.094)	16.00 (.27)	4.01 (.25)
	ts2	17.26 (1.41)	0.814 (.071)*	16.41 (.25)*	3.85 (.29)*
w 3	**tm2**	25.40 (1.29)	1.301 (.103)	16.03 (.33)	4.12 (.31)
	ts2	23.46 (1.59)*	1.150 (.065)*	16.18 (.27)*	4.23 (.35)*
w 4	**tm2**	35.46 (3.97)	1.884 (.206)	15.82 (.37)	4.32 (.31)
	ts2	31.60 (3.42)*	1.607 (.105)*	15.96 (.33)*	4.52 (.34)*
w 5	**tm2**	47.65 (6.45)	2.469 (.293)	15.93 (.33)	4.28 (.33)
	ts2	41.56 (5.29)*	2.088 (.171)*	15.98 (.32)	4.61 (.33)*

* = significant difference at 0.05 level.

Figure 1a $\dot{V}O_2$ Repeatability for subjects from Day 1 to Day 2 for TISSOT measurements.



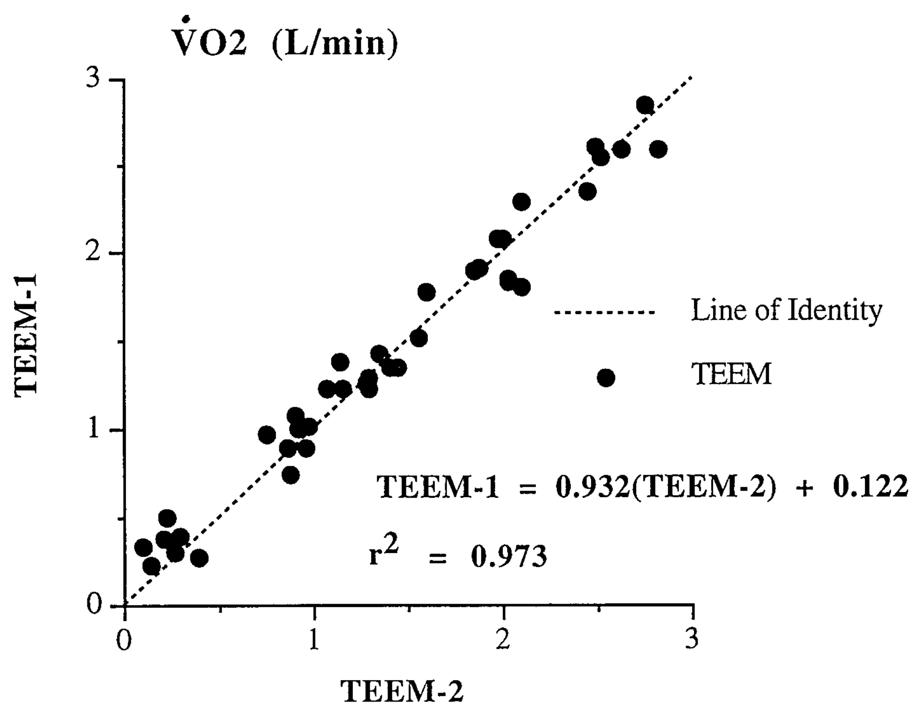


Figure 1b $\dot{V}O_2$ Repeatability for subjects from Day 1 to Day 2 for TEEM measurements.

Figure 2a $\dot{V}_E$ for TEEM versus Tissot.
TEEM = 1.191(TISSOT) - 2.426 $r^2 = 0.738$

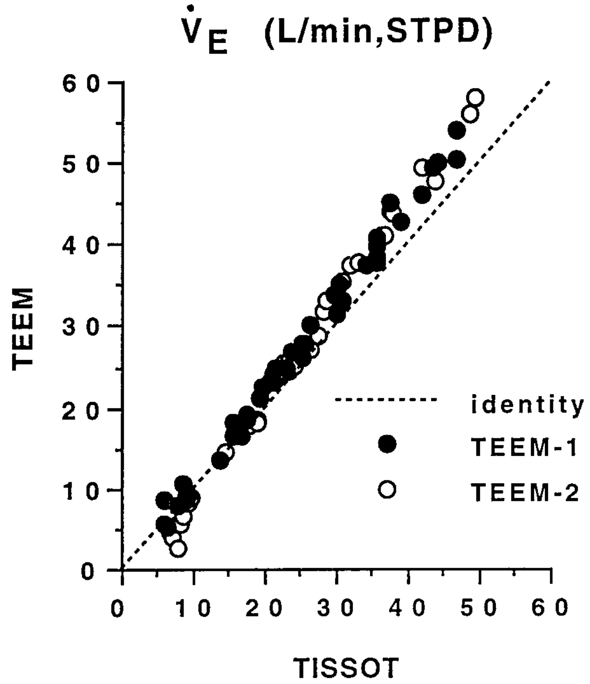
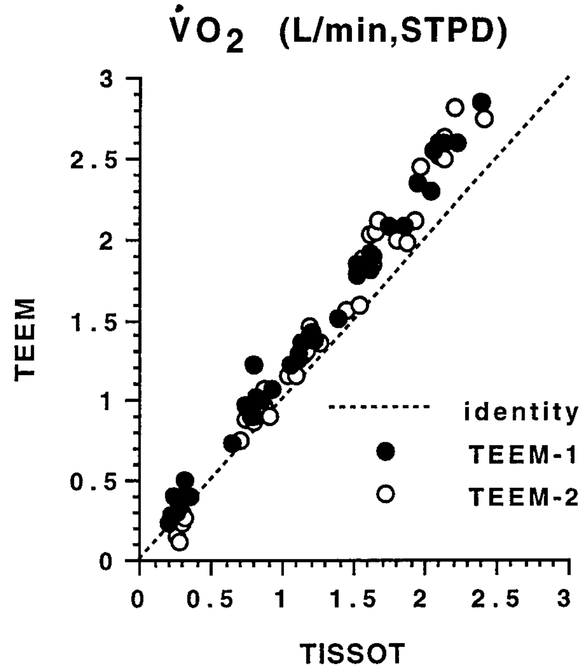


Figure 2b $\dot{V}O_2$ for TEEM versus Tissot.
TEEM = 1.198(TISSOT) - 0.33 $r^2 = 0.738$



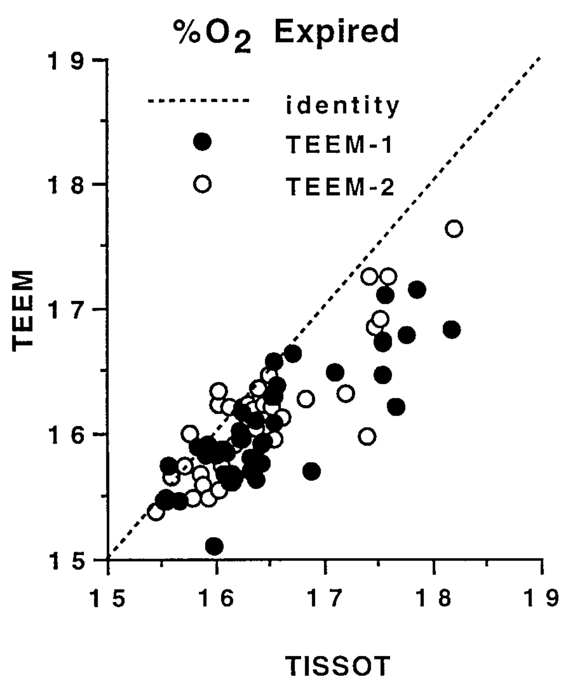


Figure 2c $\%O_2$ expired for TEEM versus Tissot.
TEEM = 0.622(TISSOT) + 0.585 $r^2 = 0.702$

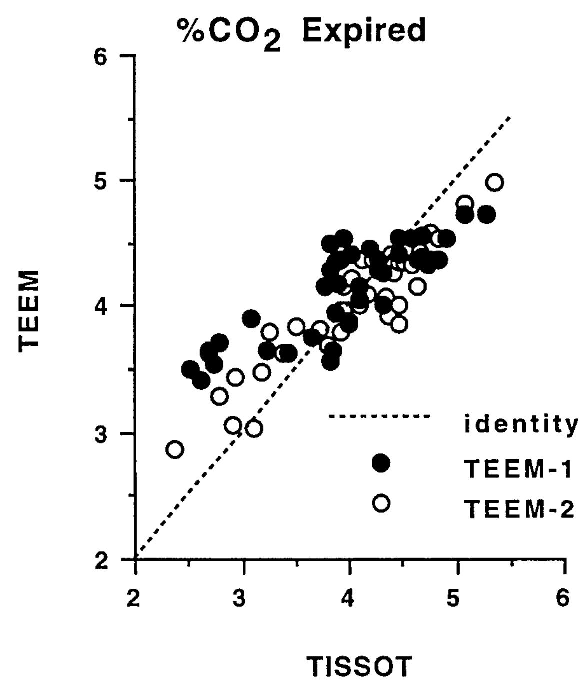


Figure 2d $\%CO_2$ expired for TEEM versus Tissot.
TEEM = 0.197(TISSOT) + 0.527 $r^2 = 0.738$

Study 2 - Methods

9. It was proposed to us by the manufacturer that perhaps our volume calibration of the TEEM 100 did not take into account any pressure effects that might occur as a result of having a two-way non-rebreathing valve downstream from the pneumotach. Also, the washout time for the Tissot might not have been sufficient to allow for thorough mixing of expired gases.

10. As a result, the same subjects underwent a second series of trials to clarify these concerns. Methods employed were identical to the first series with a few modifications. Volume calibration of the TEEM 100 pneumotach was performed with the Hans-Rudolph valve and Tissot combination in series downstream. The collection interval was extended to ten minutes. Resting and walking at 4.8 $km \cdot h^{-1}$ at 15% grade were the only two workrates used.

Study 2 - Results

11. Paired t-tests between the TEEM 100 and the Tissot gasometer again showed significant differences between means. A Newman-Keuls post-hoc analysis was performed and the results are summarized in Table 2.

Table 2: Newman-Keuls post-hoc analysis among treatment means (S.D.) for for $\dot{V}_E$, $\dot{V}O_2$, $\%O_2$ and $\%\ CO_2$. (**tm**= TEEM 100, **ts**= Tissot)

		$\dot{V}_E$	$\dot{V}O_2$	$\%O_2$	$\%CO_2$
rest	**tm1**	8.37 (1.87)	0.369 (.070)	16.64 (.32)	3.83 (.24)
	ts1	6.93 (1.32)*	0.245 (.037)*	17.44 (.20)*	3.11 (.21)*
	tm2	4.65 (1.62)	0.187 (.065)	17.05 (.39)	3.25 (.32)
	ts2	6.69 (1.12)*	0.230 (.044)*	17.61 (.19)*	2.91 (.22)*
	tm1	8.37 (1.87)	0.369 (.070)	16.64 (.32)	3.83 (.24)
	tm2	4.65 (1.62)*	0.187 (.044)*	17.05 (.39)*	3.25 (.32)*
	ts1	6.93 (1.32)	0.245 (.037)	17.44 (.20)	3.11 (.21)
	ts2	6.69 (1.12)	0.230 (.044)	17.64 (.19)	2.91 (.22)
4.8 $km \cdot h^{-1}$ 15% grade	**tm1**	50.41 (6.59)	2.481 (.327)	16.13 (.16)	4.37 (.18)
	ts1	41.60 (5.09)*	2.042 (.099)*	16.09 (.11)	4.59 (.09)*
	tm2	50.40 (5.80)	2.526 (.297)	16.09 (.24)	4.24 (.25)
	ts2	41.22 (2.81)*	2.009 (.214)*	16.14 (.12)	4.51 (.19)*
	tm1	50.41 (6.59)	2.481 (.327)	16.13 (.16)	4.37 (.18)
	tm2	50.40 (5.80)	2.526 (.297)	16.09 (.24)	4.24 (.25)*
	ts1	41.60 (5.09)	2.042 (.214)	16.09 (.11)	4.59 (.09)
	ts2	41.22 (2.81)	2.009 (.099)	16.14 (.12)	4.51 (.19)

* = significant difference at 0.05 level.

Discussion

12. The measurement of $\dot{V}O_2$ is the parameter of prime importance in the field of work physiology. Although other studies (2, 3, 5) have shown a high degree of correlation and accuracy between the TEEM 100 and their reference system (REF), our study showed an equally high correlation but a significant and unacceptable difference for $\dot{V}O_2$ measured by the TEEM 100 and the Tissot gasometer. The Tissot gasometer has been traditionally accepted as the "gold standard" for volume measurements. The present study showed that $\dot{V}O_2$ determined from the Tissot gasometer and the Ametek gas analyzers was reproducible and reliable between Day 1and Day 2 (Figure 1a). In the first study, the TEEM 100 followed this same pattern (Figure 1b). Comparisons between the two systems, however, revealed a developing trend for the TEEM 100 to overpredict $\dot{V}O_2$ with increasing workrates. This systematic overestimation of $\dot{V}O_2$ by the TEEM 100 has also been previously reported (Wideman et al, 1996). Our second study, with its modifications to the protocol, confirmed the higher $\dot{V}O_2$ values obtained by the TEEM 100. $\dot{V}O_2$ is, of course, a calculated value dependant primarily on $\dot{V}_E$, % O_2 and % CO_2, any one of which could greatly influence the calculation if it were to vary substantially from a "true" measure. Since our studies found significant differences between the TEEM 100 and the REF for $\dot{V}O_2$ at almost all workrates, the three independant variables will be discussed separately for their individual contribution to the calculated $\dot{V}O_2$.

Ventilation

13. In the present study, the TEEM 100 recorded significantly higher $\dot{V}_E$ than our REF Tissot gasometer. Novitsky et al (1995) were the only other investigators, to date, to test the TEEM 100 against a gasometer. They compared responses for all three pneumotachs and found no significant differences across all flow ranges. They tested the three pheumotachs within the specific flow range of each pneumotach. Our study utilized only the medium flow pneumotach across all flow ranges. Perhaps the ventilations during our resting phase were marginally below the operating range of this pneumotach and thus gave us the discrepancy under resting conditions. However, the flow rates during the exercise workrates were within the recommended range for use of the "medium" pneumotach. Some studies (2, 5) have found no significant difference for $\dot{V}_E$ between TEEM 100 and their REF metabolic cart. In contrast, Wideman et al. (1996) found significantly higher ventilations across workrates for the TEEM 100 than for their REF metabolic cart. Wideman also expressed some concern about moisture accumulation in the sampling lines causing a deleterious effect on $\dot{V}_E$ calculation. Since we rotated the use of our two TEEM 100's and purged all three sampling lines after use

with a syringe, "moisture" was not considered to be a factor. In addition, the calibration concern of the TEEM 100 was addressed in our second study, and yet $\dot{V}_E$ was still significantly increased for the TEEM 100. These systematically higher ventilations in the TEEM 100 would obviously account for higher $\dot{V}O_2$ results but cannot be held singly responsible for them. They must be combined with the corresponding expired gas fractions to get a true picture.

% O_2 and % CO_2

15. The expired gas concentrations can hardly be considered separately since they are both so closely related. The TEEM 100 extracts an expired sample proportional in size to the flow rate passing through the pneumotach and then routes a fixed rate to a mixing chamber for analysis. This mechanism approaches "breath by breath" sampling and may be more sensitive to instantaneous changes in expired fractions. By comparison, the REF values are a thoroughly mixed average sample and may be more indicative of a "steady state" value. Differences between the TEEM 100 and REF in O_2 extractions are more evident at low flow rates (i.e., rest). However, differences exist between methods for the measurement of expired CO_2 throughout all workrates, implying a fundamental error in the TEEM 100 CO_2 gas analyzer.

16. Although we didn't specifically do any statistical comparisons of expired % O_2 and % CO_2 for TEEM-1 vs TEEM-2 in our first study, Table1 reveals that both units responded similarly to the increasing workrate. This same finding holds true for the REF across Day 1 and Day 2. Our second study showed basically the same response at the high workrate but significant differences at rest between the TEEM 100's. This may be a function of the significant difference in $\dot{V}_E$ between the two units since expired gas concentrations are flow dependant. Other studies (2, 6) used a variety of automated metabolic measurement systems with their corresponding gas analyzers and reported no significant difference in expired gas fractions between the TEEM 100 and their REF system. Two other studies (3, 5) made no specific reference to expired gas fractions.

Conclusions

17. It becomes obvious that the combinations of possible errors for $\dot{V}_E$, % O_2 and % CO_2 expired can lead to significant differences in the calculated $\dot{V}O_2$ between the TEEM 100 and the REF. However, the high correlations between the two systems and the fact that both systems responded almost identically across workrates within themselves from day to day

indicate that the TEEM 100 is, at the least, a reliable or consistent method of measuring $\dot{V}O_2$ in laboratory and/or field trials. Its validity must be viewed with a degree of caution.

Recommendations

18. The measurement of expired volume appeared to be the most critical parameter of difference between the TEEM 100 and the Tissot gasometer. It is recommended that further investigation be done utilizing the "low" and "high" pneumotachs, within their respective operational ranges, to further clarify the discrepancies.

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This study examined the validity and reliability of a portable gas analysis system (TEEM 100) used for the measurement of oxygen consumption. Eight males were evaluated at rest and during several work intensities while expired air was collected and analysed in series with the TEEM 100 and a reference collection system (Tissot gasometer and Ametek gas analysers). Subjects were tested on 2 separate days for comparison of 2 TEEM 100 systems. The data revealed that either collection and analysis method was reliable and reproducible from day to day. However, significant and unexplained differences were found between methods for expired ventilation, expired gas fractions and the calculated oxygen consumption. These differences became greater at higher flow rates or work intensities. It was concluded that the TEEM 100 was a reliable gas exchange measurement system. Its validity, however, should be viewed with caution.

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metabolic measurement system, oxygen consumption, ventilation